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J952-4

COMPLEX CLEANUP

The Environmental Legacy of Nuclear Weapons Production

SUMMARY

CONGRESS OF THE UNITED STATES
OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

Until recently, Federal regulations to control pollution and clean up toxic wastes have been mainly focused on private industry. It is now clear that the Federal Government itself ranks high among the contributors to environmental contamination, from decades of inadequate attention to safe storage and management of toxic waste products. The environmental problems at the Department of Energy nuclear weapons facilities are among the most serious and costly to correct. Widespread contamination of soil and water, leaks from old waste burial grounds, and possible public health impacts from radioactive and hazardous releases have all contributed to congressional concerns about this problem and to a national search for feasible solutions.

The Senate Committee on Armed Services asked OTA to evaluate what is known about the contamination and public health problems at the Nuclear Weapons Complex and to investigate technological and other approaches to solutions. This report analyzes current and proposed methods of waste management and environmental restoration and evaluates the major DOE programs. It also discusses the prospects for improvement and describes certain initiatives that could enhance those prospects.

Because the characterization of the Weapons Complex waste and contamination problem is still in the early stages, it is not possible to identify and rank specific sites that represent the most serious or immediate risks. The data are not available, and even DOE has not been able to prepare a comprehensive and credible evaluation of the situation. The focus of this OTA report is therefore a comprehensive look at the problem as we now know it, the public concerns about the problem, and DOE's plans for addressing it. It focuses especially on the need for additional attention to those areas which DOE has neither the capability nor the credibility to handle. The environmental problems at the DOE Weapons Complex are serious and complicated. Decades will be required for cleanup of certain sites while others will never be returned to pristine condition. Some sites will require much long-term monitoring and control of contaminated soil and water.

Substantial assistance was received from many organizations and individuals during the course of this study. OTA sincerely appreciates the guidance received from our advisory panel, workshop participants, numerous reviewers, contributors, consultants, and contractors. We also received help in a variety of ways from the Department of Energy and its contractors during site visits and other meetings. They responded to numerous requests for data and reviewed draft documents. We also received data, comments, and other help from the Environmental Protection Agency. Without this cooperation and expert advice, OTA would not have been able to accomplish this study.

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"Man is here only for a limited time, and he borrows the natural resources of water, land and air from his children who carry on his cultural heritage to the end of time. Indian people and non-Indians must have a responsibility to these resources for generations yet unborn. One must hand over the stewardship of his natural resources to the future generations in the same condition, if not as close to the one that existed when his generation was entrusted to be the caretaker. This is the challenge of highest order this nation faces today."[1]

INTRODUCTION

During World War II the Nation's scientific elite collaborated with the military to produce the first atomic bomb—a weapon of unprecedented destructive power that later became the key element of U.S. defense strategy. The development of nuclear weapons during and after the war required an enormous dedication of talent and resources, and was the focus of prodigious technical and scientific efforts. For decades the Nation's attention was directed toward producing such weapons to provide what military planners believed to be the necessary deterrent force to avoid a superpower war. The Department of Energy and its predecessor, the Atomic Energy Commission, diligently produced tens of thousands of warheads over the past five decades at various facilities that now comprise the Nuclear Weapons Complex. (See figure 1 and table 1.)

The success of this production system, however, came at a price that few who promoted this enterprise could have anticipated. Today, it is evident that the vast network of weapons facilities, located on thousands of square miles of Federal reservations in 13 States, has produced widespread

Figure 1—Department of Energy Weapons Complex

SOURCE: Office of Technology Assessment, 1991.

[1]Delano Saluskin, Yakima Indian Nation, whose tribal lands are adjacent to the Hanford Reservation.

Table 1—The Weapons Complex (Principal Facilities List)

Type of facility	Facility	Location (State)	Size (square miles)	Management and operations contractor	Approximate current employment
Weapons research and design	Los Alamos National Laboratory	NM	75	University of California	7,400
	Sandia National Laboratory	NM	62	AT&T	8,500
	Lawrence-Livermore National Laboratory	CA	12	University of California	8,500
Materials production	Hanford Plant	WA	570	Westinghouse	13,500
	Savannah River Site	SC	300	Westinghouse	20,000
	Fernald	OH	0.2	Westinghouse	1,000
	Idaho National Engineering Laboratory	ID	893	EG&G/ Westinghouse	10,500
Weapons manufacturing	Rocky Flats Plant	CO	14	EG&G	6,000
	Oak Ridge Reservation	TN	58	Martin-Marietta	16,500
	Mound Plant	OH	0.3	EG&G	2,400
	Pinellas Plant	FL	0.2	General Electric	2,000
	Kansas City Plant	MO	0.5	Allied Signal Corp.	7,800
	Pantex Plant	TX	14	Mason & Hanger-Silas Mason	2,800
Warhead testing	Nevada Test Site	NV	1,350	Reynolds Electric	8,400
Waste disposal	Waste Isolation Pilot Plant	NM	16	Westinghouse	650

SOURCE: U.S. Department of Energy.

contamination of the environment with toxic chemicals and radionuclides. Serious questions have been raised about the potential human health threats posed by such contamination.

Niels Bohr, a Nobel laureate and one of the century's greatest physicists, maintained in 1939 that an atom bomb could not be built without "turning the country into a gigantic factory." A few years later, as Bohr was being shown around the secret sites of the Manhattan Project, Edward Teller wrote, ". . .when Bohr came to Los Alamos, I was prepared to say, 'You see. . .' But before I could open my mouth, he said, 'You see, I told you it couldn't be done without turning the whole country into a factory. You have done just that.' "[2]

It is difficult to appreciate the scale of the Nuclear Weapons Complex unless one has actually viewed the vast, tumbleweed-tossed plains of the Hanford Reservation; seen the tank farm at Savannah River where more than 50 underground tanks—each as big as the Capitol dome—house the high-level radioactive waste that inevitably results from plutonium production; or visited the area of east Tennessee, known as Site X during World War II, where the equivalent of the annual timber output of Minnesota was used to build what was then the largest roofed structure in the world. It is difficult, without seeing them, to imagine the huge concrete rooms known as "canyons" in which weapon-grade plutonium is chemically separated from other constituents in irradiated fuel elements behind thick protective walls, where the radioactivity is so intense that all work must be done by robotic manipulators.

The Nuclear Weapons Complex is an industrial empire—a collection of enormous factories devoted to metal fabrication, chemical separation processes, and electronic assembly. Like most industrial operations, these factories have generated waste, much of

[2]R. Rhodes, *The Making of the Atomic Bomb* (New York, NY: Simon & Schuster, 1986), p. 500.

Photo credit: U.S. Department of Energy

The Hanford Fuel Fabrication Plant adjacent to the Columbia River; one of a number of major facilities on the Hanford Reservation that is currently shut down.

it toxic. The past 45 years of nuclear weapons production have resulted in the release of vast quantities of hazardous chemicals and radionuclides to the environment. There is evidence that air, groundwater, surface water, sediments, and soil, as well as vegetation and wildlife, have been contaminated at most, if not all, of the Department of Energy (DOE) nuclear weapons sites. (See table 2.)

Although the Weapons Complex was developed in World War II as part of the Manhattan Project, a major expansion occurred in the early 1950s. Today, most of the operating facilities are more than 30 years old. Operations are in various stages of transition because of safety and environmental problems that have diverted attention from the production mission and because of uncertainty about the future of the entire enterprise.

Contamination of soil, sediments, surface water, and groundwater throughout the Nuclear Weapons Complex is extensive. (See table 2.) At every facility the groundwater is contaminated with radionuclides or hazardous chemicals. Most sites in nonarid locations also have surface water contamination. Millions of cubic meters of radioactive and hazardous wastes have been buried throughout the complex, and there are few adequate records of burial site locations and contents. Contaminated soils and sediments of all categories are estimated to total billions of cubic meters.

Descriptions of vast quantities of old buried waste; of contaminants in pits, ponds, and lagoons; and of the migration of contamination into water supplies serve to dramatize the problem. However, so far very little quantitative characterization of each site has been accomplished.

Many factors have contributed to the current waste and contamination problems at the weapons sites: the nature of manufacturing processes, which

Table 2—Known Contamination at Weapons Complex Facilities

Facility	Contamination		Limited corrective measures
	On-site	Off-site	
Oak Ridge Reservation	S, GW, SW, Se	SW, Se	S, SW
Pinellas Plant	GW		
Savannah River Site	S, GW, SW, Se	SW, Se	GW
Feed Materials Production Center (Fernald)	S, GW, SW, Se	GW, Se	S, GW, SW
Mound Plant	S, GW, SW, Se	GW, SW, Se	S, SW, Se
Los Alamos National Laboratory	S, GW		
Pantex Plant	GW		
Sandia National Laboratory	S, GW		
Kansas City Plant	S, GW, Se	Se	S, GW, Se
Rocky Flats Plant	S, GW, SW, Se	SW, Se	GW
Lawrence Livermore National Laboratory	S, GW, Se	GW	S, GW
Nevada Test Site	S, GW		
Hanford Plant	S, GW, SW, Se	SW, Se	
Idaho National Engineering Laboratory	S, GW, Se	S	

NOTE: S = soil; GW = groundwater; SW = surface water; Se = sediment. Information on air contamination was not obtained.

SOURCE: Office of Technology Assessment, 1991; based on U.S. Department of Energy 1987-1988 Draft Environmental Survey; interviews with U.S. Environmental Protection Agency regional offices; DOE review letter from R.P. Whitfield to Peter Johnson, June 22, 1990.

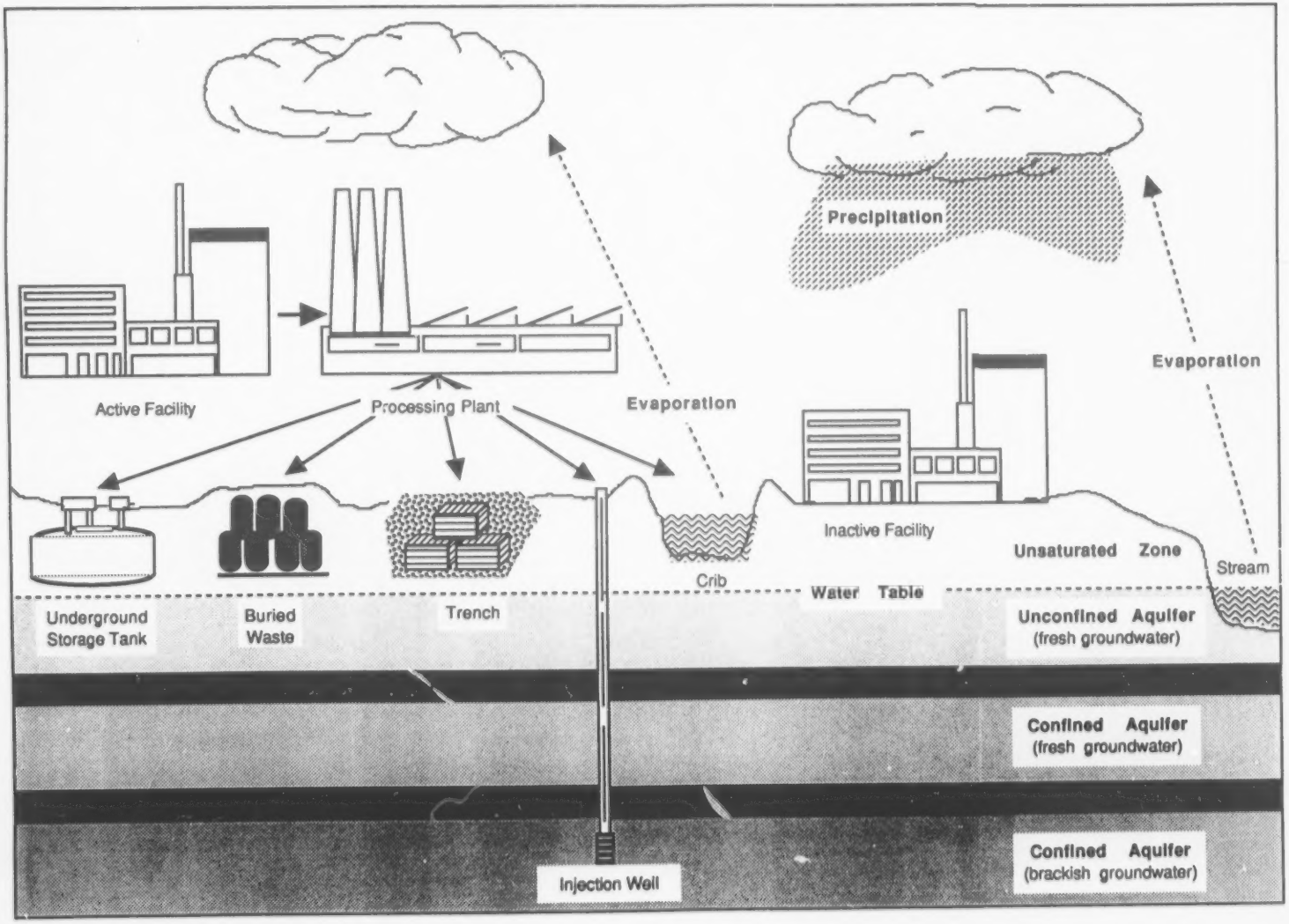
are inherently waste producing; a long history of emphasizing the urgency of weapons production in the interest of national security, to the neglect of environmental considerations; a lack of knowledge about, or attention to, the consequences of environmental contamination; and an enterprise that has operated in secrecy for decades, without any independent oversight or meaningful public scrutiny.

Public concern about these problems has now reached major proportions, and current environmental laws have forced the direction of attention and resources toward the goals of environmental restoration and safe waste management. No one fully understands the public health and environmental effects of the waste and contamination at the weapons plants, but the consensus is that they are serious enough to devote tens of billions of dollars to cleanup efforts. Even the meaning of cleanup is not fully understood, but it is generally agreed that little has really begun and several decades will be required for an acceptable level of restoration to be reached. In addition, the extent of contamination has not been fully documented, and future investigations are expected to uncover additional problems. Finally, although no consensus has been reached on how or where to dispose of it, most of the waste generated in the past and much of the waste generated in the future is clearly destined to remain at the site of generation—for decades to come.

THE ENVIRONMENTAL PROBLEM

Even though nuclear weapons production entails relatively unique processes such as plutonium recovery, and has thus created radioactive waste and contamination not found in most other settings, many more common environmental problems are also present at the weapons sites. For example, several aspects of weapons production have resulted in groundwater contamination. (See figure 2.) These types of problems are similar to those found at non-Federal industrial sites and manufacturing plants that have released toxic waste. Thus, DOE is not alone in its struggle to deal with hazardous waste and environmental contamination. Private industry has been trying to cope with the same type of problems that DOE faces today ever since the enactment of hazardous waste legislation in the 1970s and 1980s. The national program to clean up hazardous waste sites, known as Superfund, has not provided a road map for success. Common problems

Figure 2—Examples of Groundwater Contamination Sources



SOURCE: Office of Technology Assessment, 1991.

are the technical difficulties inherent in detecting and mapping the contamination at specific sites, uncertainties regarding the effectiveness of cleanup technologies, lack of qualified personnel, and ambiguities within the regulatory system. However, the scope and complexity of the contamination throughout the Weapons Complex present unprecedented challenges.

Environmental problems resulting from nuclear weapons production at the Weapons Complex have been discussed and debated over the past few years. DOE has now directed its attention to these issues and has stated publicly that it recognizes their seriousness and extent, and that it intends to expend vast resources to remediate past contamination and establish sound waste management practices for the future.

DOE is thus faced with the enormous task of environmental restoration of sites within the Weapons Complex. That task has begun. Detailed plans addressing the size and scope of the problem, and the time and resources required, have been developed only recently. DOE has prepared a Five-Year Plan that describes its goals, strategies, and specific programs for assessment and cleanup of contaminated sites and facilities to meet standards prescribed in Federal and State laws. The first Five-Year Plan was issued in 1989 and covered fiscal years 1991-95. The Five-Year Plan issued in 1990 updates the 1989 plan and covers fiscal years 1992-96. The 1990 Five-Year Plan calls for expenditures totaling more than $30 billion on environmental restoration and waste management activities for fiscal years 1992 through 1996, but most believe that this represents only the discovery phase of a program that could require hundreds of billions of dollars to complete.

DOE Weapons Complex facilities—both large and small—are spread across the Nation, from South Carolina to Washington State, and are located in both remote and populated regions. (See figure 1 and table 1.) The Feed Materials Production Center (Fernald), which has produced uranium metal for weapons, is a 1,450-acre site, a relatively small facility located 20 miles northwest of Cincinnati, OH, in a rural area with a number of farms. The Rocky Flats Plant in Colorado, which has been producing plutonium "triggers" for weapons, is also a small facility situated close to densely populated suburbs of Denver.

Photo credit: U.S. Department of Energy

An illustration of past waste disposal practices at the Weapons Complex that have contributed to current environmental problems.

Other sites are much larger than Fernald or Rocky Flats. The Hanford Reservation encompasses approximately 360,000 acres in the Columbia River Basin of southeastern Washington State. Hanford's primary mission has been to produce weapons-grade plutonium; it produced plutonium for the atom bomb dropped on Nagasaki during World War II. The Savannah River Site, built in the 1950s, produces tritium and plutonium. It consists of 192,000 acres on the north bank of the Savannah River. Most of the immediate plant environs are rural, and the surrounding area, which is heavily wooded, ranges from dry hilltops to swampland. More than 20,000 people are employed at Savannah River, making it the largest plant (in terms of employment) in the DOE Weapons Complex.

The Oak Ridge Reservation covers approximately 58,000 acres in eastern Tennessee. Oak Ridge carries out several activities including the production of weapons components. The area immediately around the reservation is predominantly rural except for the City of Oak Ridge. The City of Knoxville is about 15 miles away. The Idaho National Engineering Laboratory (INEL), where reactor fuel is reprocessed to recover uranium, has a number of facilities and conducts a variety of other activities. The largest site in terms of area, INEL covers 570,000 acres in southeastern Idaho. The site boundary is about 22 miles from the City of Idaho Falls.

Each of these sites has significant environmental contamination problems, but only in the last few

years have meaningful efforts been initiated to understand the nature and extent of the contamination and to develop more effective approaches for managing waste and reducing future contamination. The application of these efforts is just beginning, and the results are not yet evident except at a few locations. (See table 3.) At most of the sites, characterization programs—efforts to identify and quantitatively map the contamination—will continue for 5 years or more before the full extent and concentration of contaminants in the environment can be known and remediation measures can be selected. Technical, institutional, and regulatory factors will all contribute to the complexity of DOE environmental restoration and waste management programs for many years to come.

The cleanup of the Weapons Complex is framed by, and to a large extent being measured against, the goals and procedures established by a body of State and Federal environmental laws and regulations that have been developed during the past two decades. (See box A.) Over the last 5 years, DOE has gradually been required to acknowledge that cleanup of the Nuclear Weapons Complex is subject to regulation by the Environmental Protection Agency (EPA) and the States to the extent that hazardous materials are involved or a site is placed on the Superfund priority list.

The regulatory context within which cleanup must proceed is complicated. In some instances the applicable regulations are very precise and prescriptive; in other instances there is ambiguity about how to interpret the law. For some situations, there are as yet no promulgated regulations to guide cleanup managers. EPA is attempting to use the interagency agreements negotiated with individual States and the DOE facilities to resolve jurisdictional overlaps and disputes about which statute to use and whose

Box A—Key Laws and Regulations Governing Cleanup at the Nuclear Weapons Complex

RCRA—The Resource Conservation and Recovery Act (RCRA) was enacted in 1976 to address the widespread contamination problem resulting from the disposal of municipal and industrial solid waste. Managed by the U.S. Environmental Protection Agency (EPA) or EPA-authorized States, the RCRA program focuses on reducing the generation of hazardous waste and conserving energy and natural resources. DOE's Nuclear Weapons Complex facilities are subject to RCRA and therefore must apply for an EPA or State permit to treat, store, or dispose of hazardous wastes or radioactive waste mixed with hazardous pollutants. Under the Hazardous and Solid Waste Amendments of 1984 (HWSA), DOE is also required to address and eliminate contaminant releases at or from its RCRA facilities within a schedule specified by EPA. This type of activity, called corrective action, is now being carried out at most weapons sites. Releases from inactive or abandoned sites or from accidental spills are not subject to RCRA, but they may be required to be remedied according to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

CERCLA—The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (also known as Superfund) provides the U.S. Environmental Protection Agency (EPA) with the authority to assess contaminant releases from abandoned waste sites (such as those within the Nuclear Weapons Complex), categorize sites according to their risks, and include them in the National Priorities List if EPA considers their cleanup a national priority. Both radioactive and hazardous contaminants are included under CERCLA authority. Eight of the Nuclear Weapons Complex sites are currently listed by EPA as requiring cleanup under CERCLA. The Superfund Amendments and Reauthorization Act (SARA) of 1986 authorize EPA to negotiate interagency agreements with other Federal agencies and States and to oversee Federal agency efforts toward developing appropriate remedies.

NEPA—The National Environmental Policy Act (NEPA) of 1970 mandates that all Federal agencies and departments take into consideration the adverse effects that their actions may have on the environment. The Council on Environmental Quality is responsible for developing the guidance for Federal agencies to comply with the Act. NEPA requires that agency actions be reviewed early in the planning process and that the process be open to public participation. This review often results in the preparation of an Environmental Assessment or an Environmental Impact Statement (EIS), usually on a specific project. An EIS prepared for an entire program of agency activities is called a Programmatic EIS (PEIS). DOE is currently preparing a PEIS for its Five-Year Plan for waste management and environmental restoration and its modernization plan for the Nuclear Weapons Complex.

SOURCE: Office of Technology Assessment, 1991.

Table 3—Environmental Restoration Program Status at the Nuclear Weapons Complex

	Oak Ridge Reservation	Pinellas Plant	Savannah River	Fernald	Mound Plant	Los Alamos	Pantex Plant	Sandia	Kansas City	Rocky Flats	Lawrence Livermore National Laboratory (Main)	Nevada Test Site	Hanford	INEL
National Priorities List	Yes	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes
RFA or PA/SI complete[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RFI or RI work plan submitted[b]	Yes	U	No	Yes	Yes	No	No	No	U	Yes	Yes	?	U	U
CMS or FS complete[c]	P	No	No	No	No	No	No	No	Yes	P	U	No	U	Yes
Remedial or corrective actions implemented	Limited	No	Limited	Limited	Limited	No	No	No	Limited	Limited	Limited	Limited	No	Limited
Risk-exposure assessment[d]	Limited	No	Limited	Planned	Limited	Limited	No	No	No	Limited	Yes	No	No	Limited
Number of SWMUs identified to date	587	14	313	?	73	603	143	135	35	178	?	?	1500	350

NOTE: P = partial; U = underway; X = not under consideration; ? = no information.
[a]RFA = RCRA facility assessment; PA/SI = preliminary assessment/site investigation under CERCLA.
[b]RFI = RCRA facility investigation; RI = remedial investigation under CERCLA.
[c]CMS = corrective measures study under RCRA; FS = feasibility study under CERCLA.
[d]Limited risk-exposure assessment reflects work that does not necessarily meet CERCLA requirements.
SOURCE: Office of Technology Assessment, 1991; based on U.S. Department of Energy 1987-1988 Draft Environmental Survey; interviews with U.S. Environmental Protection Agency regional offices; and U.S. Department of Energy review letter from R.P. Whitfield to Peter Johnson, June 22, 1990.

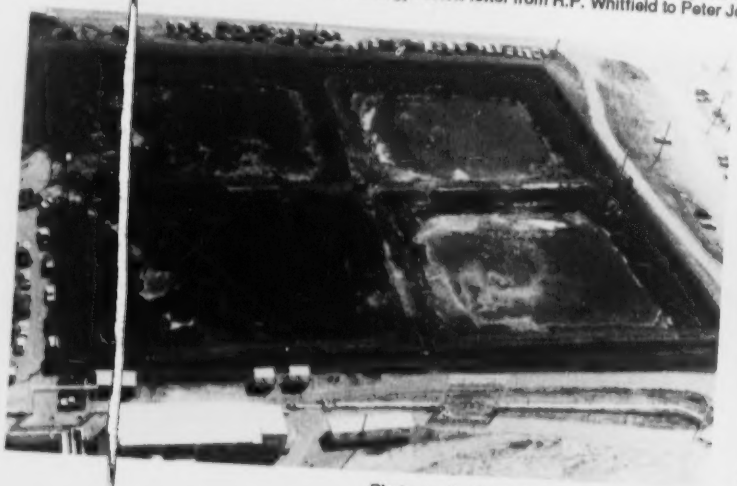


Photo credit: Martin Marietta Energy Systems

Liquid Waste Holding Ponds at the Oak Ridge Y-12 Plant before remedial action was taken.

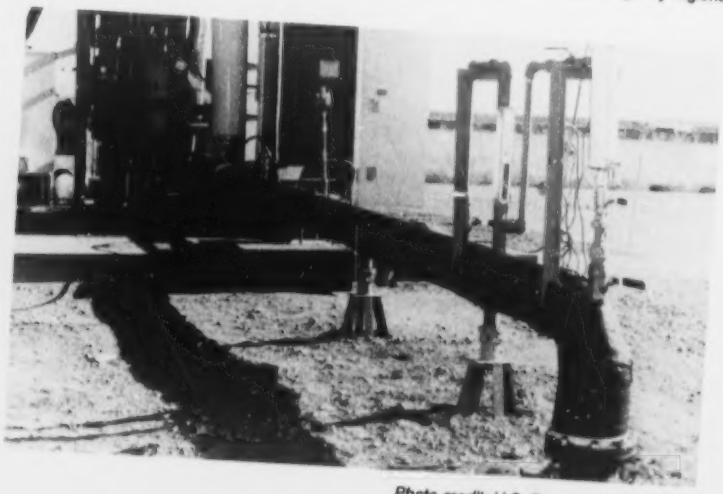


Photo credit: U.S. Department of Energy

Demonstration of technology at INEL to remove hazardous organic vapors from beneath a radioactive waste burial area.

jurisdiction takes precedence. Three party agreements are in place at three of the Weapons Complex sites and are being negotiated at some others. Where applicable, they serve as a timetable for cleanup actions and an indication of priority concerns.

The possibility that historic releases of contaminants, and current or future exposure to contaminants in the environment, might contribute to adverse health effects among off-site populations is an issue of great concern to affected communities. Information about historic releases of contaminants that have long since decayed or dispersed is relevant to health impact assessments because past exposure may increase the risks associated with current or future exposure. DOE has historically avoided public notification of releases from the weapons plants and their possible health effects. This practice has created substantial public distrust of DOE's methods and motivation.

DOE has maintained that no current contamination scenarios pose an "imminent threat" to the public health. Information about the type, extent, and concentration of current contamination, and data describing the environmental transport pathways of known contaminants, are still quite limited, however. Information about off-site contamination or the potential for off-site human exposure is especially lacking. DOE's assertion that the contamination poses no imminent health risks may be correct but is not substantiated by scientific evidence. Further, the possibility of chronic public health impacts resulting from weapons site pollution has not been addressed, and there exists no comprehensive plan for evaluating such effects.

DOE is now committed to complying with all relevant environmental regulations and is devoting enormous resources to achieving this goal. Yet the present regulatory-driven approach to the cleanup of the Weapons Complex places far more emphasis on characterizing the contamination than on investigating health impacts and may prove ill-suited to identifying public health concerns, evaluating contamination scenarios according to their potential for adverse health effects, or establishing health-based cleanup priorities.

Responsibility for conducting site-specific health studies is scattered throughout several Federal and State agencies, and limited resources have been allocated for such efforts. The current approach to health investigations mandated by environmental laws and agreed to in interagency negotiations is likely to omit many important health objectives.

THE OFFICE OF TECHNOLOGY ASSESSMENT FINDINGS

Over the past year the Office of Technology Assessment (OTA) has studied current and proposed approaches to waste management and environmental restoration at the Nuclear Weapons Complex. OTA's analyses focused on the following areas: 1) evaluating immediate problems and needs that could benefit most in the near term from additional emphasis and resources, 2) assessing technologies for waste management and environmental restoration, and 3) investigating approaches for setting priorities and allocating resources. OTA has also evaluated institutional, management, and regulatory issues relating to these matters and has assessed prospects for the future and the opportunities for enhancing these prospects. Box B presents the key findings from this assessment.

The environmental restoration program underway at the Weapons Complex is in the very early stages, and little actual cleanup work has been done. At a few sites, some simple containment and stabilization activities have been performed by capping or by removing contaminated soil and storing it elsewhere in a more controlled form. Many remediation measures have limited capabilities; thus many sites may never be returned to a "contaminant-free" condition or a condition suitable for unrestricted public access. *OTA's analyses show that it may be impossible with current technology to remove contaminants from certain groundwater plumes (see box C) and deeply buried soil or, even if possible, it may be extremely expensive or require prolonged periods of operation.* In these cases, some aggressive efforts may be required to contain the materials and prevent further migration to the extent possible, while at the same time monitoring carefully any changes in conditions. *In the future, much more containment technology and point-of-use monitoring and control will have to be applied to some sites.*

Technologies that could effectively remediate certain sites with extensive or complex contamination of soil, groundwater, sediments, and surface water either are not available or cannot be applied with the resources now contemplated. New technologies may be available in the future, but the most promising are still in the very early stages and will

Box B—Key Findings

- The waste and contamination problems at the DOE Weapons Complex are serious and complicated, and many public concerns about potential health and environmental impacts have not yet been addressed.
- DOE, other Federal agencies, and the States are trying to carry out their legally mandated cleanup responsibilities, but they presently lack the necessary personnel and infrastructure, and they have yet to develop an effective process for public involvement in setting priorities and making important decisions. Despite recent laudable efforts at changing the DOE culture, substantial credibility and public acceptance problems continue to hinder progress.
- The environmental program now underway at the Weapons Complex is in the very early stages, and little actual cleanup has been done. It may be impossible with current technology to remove contaminants from many groundwater plumes and deeply buried soils within reasonable bounds of time and cost. Many sites may never be returned to a condition suitable for unrestricted public access.
- Despite DOE statements about the lack of imminent off-site health threats due to the contamination, possible public health effects have not been investigated adequately. The current regulatory process is not sufficient to effectively identify urgent health-based remediation needs or to comprehensively evaluate possible public health impacts. Among the missing elements are a coherent strategy for evaluating potential off-site human exposure to radioactive and hazardous contaminants, a coordinated and scientifically sophisticated approach for evaluating potential health impacts from contamination, and an open process for public involvement in identifying risks and setting priorities for reducing risks.
- Because of the limitations of existing cleanup technologies it is prudent to invest in promising new developments; however, such efforts should not delay addressing situations in which containment and monitoring are warranted now. OTA finds that a technology development program will be most beneficial if it is focused on the most serious contamination problems identified by possible health risks.
- DOE's stated goal—to clean up all weapons sites within 30 years—is unfounded because it is not based on meaningful estimates of work to be done, the level of cleanup to be accomplished, or the availability of technologies to achieve certain cleanup levels. Neither DOE nor any other agency has been able to prepare reliable cost estimates for the total cleanup.
- DOE currently has large quantities of radioactive and hazardous waste in storage at all sites, often under marginal conditions. There will be an increasing need to store waste safely on-site for fairly long periods until disposal alternatives are available. Adequate and workable standards and criteria for improved storage and treatment on-site are urgently needed.

require many years of research, development, and testing at specific sites. *OTA's analysis shows that whereas investing in promising new technologies may be productive, it should not delay immediate efforts to contain contamination that has the potential for wider dispersion or rapid migration and to establish programs that continually monitor contaminant movements.*

OTA also finds that it may be more effective to invest substantial time and resources in the intensive development of a few technologies designed to address the most serious contamination problems than to make smaller investments in a range of potential innovations. In addition, conventional technologies require testing and evaluation at actual waste sites to confirm their effectiveness or understand their limitations.

OTA analysis indicates that the DOE goal stated in the Five-Year Plan and elsewhere—to clean up all weapons sites within 30 years—is unfounded because it is not based on meaningful estimates of the work to be done or the level of cleanup to be accomplished at the end of that time. The extent of environmental restoration work required at each site by current regulations and cleanup standards will not be known until characterization activities and other studies are completed. Some situations could require investigation and remediation beyond that specified in current regulations. Furthermore, acceptable cleanup levels have yet to be determined for many DOE weapons sites. *Without knowledge of the cleanup*

Box C—Contaminated Groundwater Can Be Difficult To Clean Up

Groundwater can become contaminated from numerous sources. At the Nuclear Weapons Complex, sources include accidents and spills; intentional introduction of waste into the ground (cribs, surface impoundments, underground injection wells, landfills); and failure of containment methods (underground storage tanks).

Groundwater contamination is very site-specific in terms of the contaminants present and their behavior. Groundwater contamination is such a difficult problem to characterize and clean up because the environment is not uniform. In general, the less uniform the environment (such as fractured limestone at Oak Ridge or the presence of clay lenses at Savannah River), the more difficult it is to characterize contamination problems and clean them up. Some contaminants will be easier to find and clean up than others. For example, those contaminants that move with water are easier to find than those that do not.

Contaminants at the Weapons Complex include radionuclides, heavy metals, nitrates, and organic contaminants. Often these are present as complex mixtures that affect the mobility and fate of individual contaminants in the subsurface. Contaminants also behave in different ways, depending on the characteristics of a site. As contaminants move through the ground to an aquifer, many processes occur that affect the amount or concentration of the contamination by the time it reaches a receptor of concern such as a well or surface water. The processes may also affect the performance of remediation techniques. Many of these processes, however, are not well understood.

Some contaminants adsorb onto soil particles in the unsaturated zone or onto the aquifer media, thereby slowing their movement and possibly preventing groundwater contamination. Contaminants may also form or adsorb onto colloidal particles, which allows them to move with, or faster than, the average groundwater flow. Flow can result from an apparently unrelated force, such as the flow of water and contaminants due to a thermal or electrical gradient instead of the expected hydraulic gradient. Chemical reactions and biotransformations may occur, possibly changing the toxicity or mobility of contaminants. Some contaminants dissolve and move with the water; some are in the gas phase; others are nonaqueous phase liquids; some are more dense than water and may move in a direction different from groundwater; others may be less dense than water and float on top of it.

Contaminants that dissolve in water can often be extracted from groundwater and cleaned up with pump and treat techniques. This is the most commonly used procedure to clean up contaminated groundwater. Pump and treat can successfully remove great quantities of contaminants; however, the approach often takes much longer than originally planned to reduce contaminants to desired levels. Pumping can often be an effective way to prevent the spread of groundwater contamination and even reduce the size of a contaminated plume, but in some cases it may not be possible to restore aquifers by pump and treat methods. EPA recognizes that, with current technologies, complete groundwater restoration may not be practicable in some circumstances, such as highly contaminated zones near the source of contamination that remain contaminated at levels preventing beneficial use. Long-term containment, natural attenuation, wellhead treatment or alternate water supply, and institutional controls to restrict water use may be necessary rather than attempting to restore an aquifer to health-based standards.

Because contaminated groundwater is so difficult to clean up, it is especially important to prevent contamination from occurring in the first place and to prevent it from spreading further once it has occurred.

SOURCE: Office of Technology Assessment, 1991.

levels to be achieved by the end of 30 years, or the technologies required to achieve such levels, DOE cannot develop reliable cost estimates for the total cleanup. Thus, 30 years may prove too short a time to complete the cleanup to a reasonable degree, and the enormous resources required to clean up within that period may not be available. Some of the sites may never be restored to a condition permitting public access and use; thus, cleanup goals would need to be revised.

OTA has reviewed the current approach to waste management throughout the Weapons Complex, with particular attention to the disposal of some of the more hazardous and toxic materials in storage or being generated—especially high-level radioactive waste, transuranic waste, and mixed radioactive and hazardous waste. (These types of waste are defined in box D.) OTA has also reviewed the status of regulations and standards that are vital to major decisions on waste disposal. *Until safe geologic disposal capabilities are available, there will be an increasing need to store waste safely on-site for long periods (decades) and to provide more detailed and careful contingency plans for such storage*. The

Box D—Types of Waste

High-Level Waste (HLW): The highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation.

Transuranic (TRU) Waste: Without regard to source or form, waste that is contaminated with alpha-emitting transuranium nuclides with half-lives longer than 20 years and concentrations higher than 100 nanocuries per gram at the time of assay.

Low-Level Waste (LLW): Waste that contains radioactivity and is not classified as high-level waste, transuranic waste, spent nuclear fuel, or byproduct material. Test specimens of fissionable material irradiated for research and development only, and not for the production of power or plutonium, may be classified as low-level waste, provided the concentration of transuranics is lower than 100 nanocuries per gram.

Hazardous Waste: Waste that is designated hazardous under RCRA and EPA regulations.

Mixed Waste: Waste containing both radioactive and hazardous components as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act, respectively.

SOURCE: U.S. Department of Energy Order No. 5820.2A.

Photo credit: U.S. Department of Energy

Sludge removal from an injection well contaminated with tritium and hazardous chemicals at INEL.

prospects for improving operating and management practices and reducing the risk of future contamination are also discussed. *If past problems are to be avoided, future waste management practices must meet stringent criteria for safe storage, treatment, and disposal.*

OTA has analyzed the environmental contamination and public health problems throughout the DOE Weapons Complex, as they are understood today. *The analysis shows that, despite some DOE statements about the lack of immediate health threats, public health concerns have still not been investigated adequately by DOE or by other government agencies.* Off-site health impacts are a plausible, but unproven, consequence of environmental contamination from the Nuclear Weapons Complex. Published reports and available data can neither demonstrate nor rule out the possibility that adverse public health impacts have occurred or will occur as a result of weapons site pollution. Investigations beyond those already completed or planned will be necessary to pursue questions about the occurrence of off-site health effects and to produce the information required to identify the most pressing cleanup priorities. (See box E.)

OTA has not attempted to conduct its own investigation of actual or potential public health threats. It has noted, however, that a more aggressive and coordinated investigatory process—conducted by qualified and independent parties, with early and continuous public involvement—that can assess public health issues and trace public concerns about health impacts to their possible sources is necessary to identify problems requiring immediate attention and to demonstrate more convincingly that public health is being protected. *OTA has concluded that current health assessment efforts are unlikely to efficiently produce the data necessary to set health-*

Box E—Tracing the Toxic Trail From Contaminant Source to Health Effects

Linking an environmental contaminant to a particular human health effect requires tracing a long and complicated trail from the original source of a pollutant to the particular symptom, disease, or other biological end point suffered by an individual or a population. The trail may be years or even decades old, and documentation of the original source term may not be ideal. The course of a contaminant's progress may literally be underground, where its route and direction cannot be visualized directly, or the pollutant may have been dispersed by winds long ago. Once a chemical or radionuclide is loose in the environment, it can interact with other substances, change chemical form, become diluted, transfer from one medium to another, piggyback on other substances that transport it long distances, or accumulate in geophysical sinks or in plants and animals. Tracking such escape routes, mapping the present whereabouts of the contaminant, and designing measures to contain or eliminate the pollution are the purposes behind the remedial investigation/feasibility study (RI/FS) and facility investigation (RFI) processes of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA), respectively. Virtually every aspect of the cleanup effort thus far has involved efforts to identify, trace, and quantify environmental contamination.

Most of the requirements stipulated by environmental regulations, and all Department of Energy (DOE) cleanup efforts to date, address the assessment of the path and behavior of contaminants as they move into the environment and become potentially accessible to human contact. Very little effort has been directed toward investigating the *effects* of the contamination on human health or the environment.

Environmental health assessments focus on that part of the "toxic trail" leading from human exposure to health effect. For health investigators, information describing the types and whereabouts of the contamination is just the beginning of the puzzle. Environmental health assessments attempt to follow the progress of an environmental toxicant from its presentation in the ambient environment at the point of potential human exposure through its absorption into the body and subsequent metabolism, accumulation, or elimination, and to relate these phenomena of molecular biology to observable expressions of dysfunction or to overt disease.

Ultimately, the scientific challenge is to determine as accurately as possible each term in the path that links the source of the contaminant with the particular biological end points or health effects, and to understand the molecular mechanisms that connect them. However, the present state of scientific knowledge regarding the effects of exogenous chemicals on human biology is very limited.

Environmental health assessments must be designed and interpreted carefully, lest the many unknowns and the large ranges of uncertainty in individual pieces of the assessment combine to yield ambiguous or even misleading results. Judgments are inevitably integrated into any assessment of environmental health effects, whether the methods used involve large epidemiological studies or the most rigidly codified quantitative risk assessment. The scientific credibility of such assessments is enhanced when those judgments are made explicit and research efforts are conducted in an open, unbiased manner.

A variety of research methodologies can be applied to the investigation of possible health effects resulting from environmental pollution, including exposure assessments, exposure or disease registries, medical surveillance programs, epidemiological studies and risk assessments. All of these approaches necessarily incorporate estimates and uncertainties; no single method is capable of definitively proving the existence or absence of adverse health effects due to environmental contamination. Because of the many gaps in the scientific understanding of the health impacts of environmental toxicants, and a relative lack of experience and resources within the environmental health research community, many questions about the health effects due to weapons site contaminants may remain unanswered for a long time to come.

based environmental restoration priorities. OTA has also noted that research on the biological consequences of weapons site contamination has not received the attention or resources necessary to understand the potential health impacts of contamination and to establish appropriate cleanup goals.

OTA has reviewed the status of major cleanup efforts throughout the Weapons Complex and noted the objectives that those efforts must meet. At every major site in the complex, radioactive and hazardous contaminants are present in soil, sediments, waste burial grounds, groundwater, or surface water. In many cases, these contaminants are migrating toward nearby populations; in some cases, off-site contamination of groundwater, sediments, and surface water has been detected. Contaminants include a wide range of radionuclides, metals, organic

compounds, and other substances that could have adverse health consequences if they reach human receptors in sufficiently large concentrations. (See table 2.)

OTA has concluded that an aggressive, scientifically sophisticated, site-specific, and open evaluation of possible off-site health effects by independent environmental health professionals is needed. Identification of those situations that pose a significant threat of current or future off-site exposure, and hence have the potential for adverse health effects, might provide a manageable near-term focus for remediation. Exposure assessments could provide some immediate health-based priorities to guide environmental restoration and technology development, in addition to identifying the direction of—or possible lack of need for—further health investigations.

Although such an approach could divert certain functions from DOE to another agency, it would do so in an area where DOE has little capability and credibility—an area that is currently neglected and crucial to public support of the cleanup as a whole. There may be concerns that such a process would delay cleanup work now underway. In certain cases, however, a delay in remediation might be warranted and could lead to improved outcomes if actual health impacts are better understood. *Unless and until the contamination-related health issues of most concern to the public are recognized and addressed, the most ambitious, sophisticated, and well-meaning cleanup plans and activities will likely meet with skepticism, suspicion, and legal challenges.*

Finally, OTA notes that, despite recent laudable efforts, significant changes in DOE's practices are still necessary to develop credibility and public acceptance of its plans for waste management and environmental restoration. To achieve the needed changes, aggressive efforts are required in the following areas: substituting independent, external regulation for DOE self-regulation wherever feasible; providing long-term, capable, independent oversight in matters for which DOE continues to retain primary responsibility; making information openly available and easily accessible to the public; and promoting active and continuous public involvement—at the National, State, regional, and local levels—in decisions about waste management and environmental restoration objectives, priorities, and activities.

POLICY INITIATIVES TO IMPROVE CLEANUP PROSPECTS

DOE, other Federal agencies, and the States are attempting to carry out their legally mandated responsibilities with respect to waste management and environmental restoration at the Weapons Complex. The cleanup effort is being hampered, however, by three fundamental problems. First, the technical and institutional resources and processes to make and implement sound, publicly acceptable decisions are not presently in place. Moreover, current agency plans do not adequately address these missing elements. Second, DOE's current decisions lack credibility because of past failures by DOE and its predecessor agencies to deal effectively with environmental contamination and to make full public disclosure regarding the contamination and its impact. Yet, the current decisionmaking process does not include adequate mechanisms for involving the public effectively in environmental restoration and waste management decisions. Third, the current approach to cleanup does not include a coherent and comprehensive strategy for evaluating potential off-site human exposure to Weapons Complex waste and contamination and for investigating potential health impacts due to the contamination. As a result, no reliable basis exists for understanding, identifying, and reducing potential public health risks; addressing community concerns about health impacts; and setting health-based funding priorities.

For these reasons, *OTA finds that the prospects for effective cleanup of the Weapons Complex in the next several decades are poor and that significant policy initiatives are required if those prospects are to be improved.* These initiatives should be directed toward improving the performance of DOE and other government entities involved in conducting or regulating waste management and environmental restoration activities, and enhancing the credibility and public acceptability of the decisionmaking processes for waste management and environmental restoration.

The policy initiatives outlined below, and summarized in box F, are aimed mainly at improving and strengthening the decisionmaking process for setting and meeting cleanup objectives. Congressional oversight could improve the performance and coordination of involved agencies and provide more effective approaches to safe waste storage and

Box F—Policy Initiatives To Improve Cleanup Prospects

I. Increase congressional oversight of environmental restoration and waste management activities that require improved performance by the responsible agencies.

Congress could increase its oversight of DOE, EPA, and other Federal agencies to develop and implement improved programs to deal promptly with the following matters:

- strengthen agency personnel,
- plan for safe interim waste storage,
- improve technology development,
- increase public access to information,
- coordinate and accelerate standard-setting, and
- strengthen site monitoring programs.

II. Enhance the structure and process for assessing the public health impacts of Weapons Complex waste and contamination.

Congress could establish the following institutional mechanisms to evaluate potential off-site health impacts:

- a new and separate health assessment office,
- health "Tiger Teams" to conduct exposure assessments at each site, and
- a national independent environmental health commission.

III. Develop a structure and process to provide public participation in key cleanup policy and technical decisions.

Congress could establish the following institutional mechanisms:

- advisory boards with technical staff at each site and
- a national coordinating and advisory board.

IV. Establish a national mechanism to provide outside regulation of DOE radioactive waste management programs.

Congress could authorize an institution to regulate those aspects of radioactive waste management activities now subject exclusively to DOE's authority. These functions could be given to:

- a new national body or
- an existing body such as the Nuclear Regulatory Commission or EPA.

disposal, technological development, public access to information, and other aspects of the cleanup. The conduct of health assessments by independent entities with environmental health expertise could improve prospects for establishing health-based priorities to be used in the decisionmaking process. Establishing site-specific advisory bodies to provide independent public policy and technical oversight could improve prospects for open, credible, and cooperative decisionmaking processes on key aspects of the cleanup. Substituting independent regulatory authority for DOE's self-regulation in radioactive waste management activities could enhance the credibility and quality of current and future waste management decisions.

The following policy initiatives could improve cleanup prospects and provide better assurances that sound waste management practices will prevail in the future:

I. ***Increase congressional oversight of environmental restoration and waste management activities that require improved performance by the responsible agencies.***

Congress could increase its oversight of DOE, EPA, and other relevant Federal agencies to ensure that the agencies implement existing legislative authority to effectively conduct and properly coordinate waste management and environmental restoration activities. This oversight could usefully be directed toward the responsible agencies to improve their performance in the following areas that could benefit from prompt attention:

1. *Strengthen Agency Personnel*

Agencies need to act as soon as possible to specify personnel requirements and develop strategies for meeting personnel needs. Congress could encourage DOE, EPA, and other involved agencies, in cooperation with the States, to prepare a coordinated plan that identifies personnel needs for the cleanup program and outlines a process for developing the cadre of professionals required.

2. *Plan for Safe Waste Storage*

Repository delays have affected key aspects of DOE HLW and TRU waste management strategies; regulations pertaining to [illegible] require changes in some of DOE's earlier plans. To enhance prospects for safe on-site storage of waste, DOE could prepare a detailed plan for long-term interim storage of high-level and transuranic waste and for storing and treating mixed radioactive and hazardous waste.

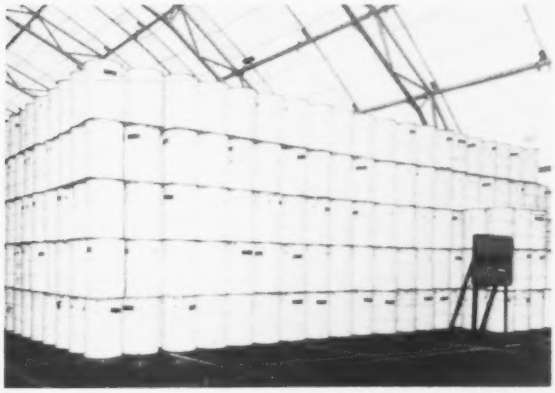


Photo credit: U.S. Department of Energy

Transuranic waste in drums awaiting shipment to a repository for disposal.

3. Improve Technology Development

The procedure for developing and implementing more effective technologies could be improved by more focused analysis of the requirements and alternative solutions for the most important cleanup problems. DOE could accelerate efforts to structure a program clearly identifying immediate technological needs and timely solutions to the more urgent contamination problems.

4. Increase Public Access to Information

New procedures are needed to provide the public with all information relevant to waste management and environmental activities. DOE could accelerate its declassification efforts relevant to waste management and environmental restoration; promptly make requested material available; and more aggressively notify interested parties of meetings, hearings, comment periods, and the availability of new materials.

5. Coordinate and Accelerate Standard-Setting

Adequate standards relevant to the cleanup, especially those for radioactive soils and sediments and for mixed waste, need to be developed in a timely manner. DOE, EPA, and other involved agencies could establish more effective coordination among and within agencies and assign appropriate staff to set, apply, and enforce health-based standards.

6. Strengthen Site Monitoring Programs

If some sites or portions of sites cannot be cleaned to the point of unrestricted use, institutional controls (including continuous monitoring and oversight, as well as notification and warnings) will be necessary to ensure that the public and the environment are not adversely affected. DOE could strengthen its programs for monitoring and control of those sites that may continue to have contamination.

II. ***Enhance the structure and process for assessing the public health impacts from Weapons Complex waste and contamination.***

Congress could establish a structure and process to evaluate potential health impacts from the weapons facilities as a basis for setting cleanup priorities.

To implement this initiative, Congress could establish a new office within the Department of Health and Human Services (HHS), EPA, or other agency to coordinate and direct site-specific health assessments, and State-organized health studies. Congress could direct this office, as its first task, to establish health "Tiger Teams" to conduct comprehensive assessments of the potential for human exposure to contamination at each site. To provide the necessary expert advice to this office, Congress could further establish a national, independent environmental health commission reporting to Congress to provide guidance regarding exposure assessments, health effects evaluations, and health research needs related to the cleanup. Congress could require DOE to make information about past environmental releases and current contamination available to the Tiger Teams, the scientific community, and the public.

This policy initiative could strengthen the assessment of potential off-site health impacts and thus improve the prospects that health-based priorities will be established and implemented. The initiative could provide accelerated, scientifically rigorous exposure assessments to determine the most urgent health issues posed by the contaminants and establish a coordinated approach to site-specific assessments that efficiently and comprehensively evaluates the past, current, and potential public health impacts of contamination. Exposure assessments with broad public involvement could better equip the responsible agencies and the public to develop and implement health-based cleanup priorities in a timely manner. Finally, this initiative could improve the prospects that specific community concerns about off-site health effects are addressed.

Photo credit: U.S. Department of Energy

Radioactive contaminated waste on a concrete pad at Fernald awaiting shipment off-site.

III. ***Develop a structure and process to provide public participation in key cleanup policy and technical decisions.***

Congress could establish a structure and process to provide public participation in key cleanup policy and technical decisions.

To implement this policy initiative, Congress could establish advisory boards with full-time technical staff at each site to provide both policy and technical advice to DOE, EPA, HHS, and the States. These boards could consider issues relating to cleaning up past contamination, assessing and reducing public health risks, and safely storing and disposing of past waste. By having access to the information, technical support, and other resources needed to participate effectively in all aspects of the cleanup decisionmaking process, the boards could foster openness, trust, and cooperation among interested parties which is not being achieved at present. Congress could also establish a national board including representatives from the site-specific boards to coordinate the activities of the site-specific boards and provide advice to the headquarters level of involved Federal agencies regarding national policy and technical issues.

This policy initiative addresses the need for effective public involvement in environmental restoration decisions at each of the sites. OTA believes that those decisions could be improved by providing independent input to key policy and technical issues and by involving the public in the development of site-specific, health-based cleanup priorities.

IV. ***Establish a national mechanism to provide outside regulation of DOE radioactive waste management programs.***

Congress could authorize an institution other than DOE to regulate those aspects of the radioactive waste management activities now subject exclu-

sively to DOE authority and over which no other agency now has such authority.

To implement this policy initiative, Congress could either establish a permanent, full-time, independent national commission having regulatory and enforcement authority with respect to radioactive waste management activities at the Weapons Complex or authorize an existing body such as the Nuclear Regulatory Commission or EPA to exercise these functions.

This policy initiative could improve the credibility and effectiveness of the decisionmaking process for waste management by limiting DOE self-regulation and providing appropriate independent regulation of the treatment, storage, and disposal of radioactive waste.

CONCLUSION

Progress in cleaning up the waste and contamination at the Weapons Complex is being hampered by a paucity of data and qualified personnel, inadequate efforts to assess possible off-site health impacts, lack of ready technical solutions, and public skepticism about government agency decisions and activities relating to waste management and environmental restoration. The policy initiatives outlined above are aimed at improving and strengthening the decisionmaking process for setting and meeting cleanup objectives.

Increased congressional oversight could improve prospects for enhancing the agency infrastructure, accelerating standard-setting, and providing more effective approaches to site characterization and remediation, waste storage and disposal, technological development, priority setting, and other aspects of the cleanup. The direction and coordination of site-specific health assessments by an independent and authoritative entity could improve prospects for achieving scientifically sound and credible evaluations of possible off-site health impacts, resolving community health concerns and developing health-based cleanup priorities. Establishing site-specific advisory bodies to provide independent policy and technical advice could improve prospects for open, credible, and cooperative decisionmaking on key aspects of the cleanup. Substituting independent regulatory authority for DOE's self-regulation in radioactive waste management activities could enhance the credibility and quality of waste management decisions.

Although the cleanup will be a long and difficult task, OTA's analyses indicate that the policy initiatives outlined above could significantly improve the prospects that sound and credible cleanup decisions will be made.

NOTE: Copies of the report "Complex Cleanup: The Environmental Legacy of Nuclear Weapons Production" can be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402-9325, GPO stock No. 052-003-01222-7.

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The Office of Technology Assessment (OTA) was created in 1972 as an analytical arm of Congress. OTA's basic function is to help legislative policymakers anticipate and plan for the consequences of technological changes and to examine the many ways, expected and unexpected, in which technology affects people's lives. The assessment of technology calls for exploration of the physical, biological, economic, social, and political impacts that can result from applications of scientific knowledge. OTA provides Congress with independent and timely information about the potential effects—both beneficial and harmful—of technological applications.

Requests for studies are made by chairmen of standing committees of the House of Representatives or Senate; by the Technology Assessment Board, the governing body of OTA; or by the Director of OTA in consultation with the Board.

The Technology Assessment Board is composed of six members of the House, six members of the Senate, and the OTA Director, who is a nonvoting member.

OTA has studies under way in nine program areas: energy and materials; industry, technology, and employment; international security and commerce; biological applications; food and renewable resources; health; communication and information technologies; oceans and environment; and science, education, and transportation.

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